Split Hopkinson Resonant Bar Experiment for Fracture Poroelasticity

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RESEARCH OBJECTIVES

The objective of this research is to examine the dynamic poroelastic behavior of single fractures and faults in rock for a range of hydraulic properties. To this day, laboratory experiments on the dynamic properties of single fractures have been conducted nearly exclusively using ultrasonic waves. When extrapolating the laboratory-measured properties to the field, however, large differences in the seismic wave frequencies used in the laboratory (~1 MHz) and the field (~100 Hz–10 kHz) may result, causing significant discrepancies. To overcome this difficulty, we developed an acoustic resonant bar apparatus that can measure the complex elastic moduli of rocks containing fractures in the sonic range (~1 kHz).

Figure 1. Fracture compliance measurement via split Hopkinson resonant bar tests. A sample assembly containing a short rock core suspended within a metal cage is acoustically resonated within a confining cell (A). Using this setup, normal (compressional) and shear compliances of fractures under dry and water-saturated conditions are measured as a function of applied normal stress (B).

APPROACH

Conventional resonant bar tests have been used since the beginning of laboratory acoustic testing of materials. Typically, a resonant bar test measures a resonance frequency and damping (attenuation) of vibrations in a long, bar-shaped sample and relates them to the complex elastic moduli of the material. Since the frequency, or rather, wavelength, of the resonance is determined by the dimension of the sample, we require a longer sample for measuring the moduli at low frequencies. For testing rocks, this can be a problem, since rock cores longer than several inches (corresponding to frequencies of tens to hundreds of kilohertz) are difficult to obtain.

We have adopted an experimental setup from an acoustic test called the split Hopkinson bar test, which employs a short core or disk-shaped rock sample sandwiched between two long slender metal bars (see Figure 1). While a conventional split Hopkinson bar test measures reflected and transmitted waves across the sample, our setup measures the resonance of the whole system, which allows us to determine the material properties more accurately. Because of the extra length and mass added by the attached metal bars, measured resonance frequencies are reduced, which allows us to measure low-frequency properties of the rock sample. The complex elastic moduli of the rock sample are determined via nonlinear numerical inversion, using a one-dimensional wave propagation model, from measured resonance frequencies and attenuation (measured from the width of the resonance peak). For determining the dynamic properties of a fracture, we conduct two sets of measurements, before and after the fracture is introduced in a rock core. The difference in the apparent elastic moduli of the rock core provides the properties of the fracture.

ACCOMPLISHMENTS

We developed an experimental apparatus for measuring acoustic resonance of short core samples (one to four inches in length) under hydrostatic pressure from high-pressure gas. Concurrently, we developed a complex-elastic moduli inversion technique that allows us to extract the moduli of a sample from measured apparent elastic moduli. An important recent improvement was the consideration of the end-effect, which resulted in an apparent increase in the Young's modulus of a short core sample for materials with a high-Poisson's ratio. A series of experiments was conducted on both synthetic materials with known material properties, and natural geomaterials—including unconsolidated sand, well-consolidated sandstone and carbonates (limestone and chalk), and rock cores containing fractures.

SIGNIFICANCE OF FINDINGS

Experiments for a fractured sandstone core demonstrated that the split Hopkinson resonant bar test is very sensitive to the changes in fracture properties: changes in fracture compliance that result in less than 0.1% of wave transmission coefficient across a fracture can be resolved. This allows us to use the current experimental setup for studying the dynamic poroelasticity of a fracture, with good resolution.

RELATED PUBLICATION

Liu, Z., J.W. Rector, K.T. Nihei, L. Tomutsa, L.R. Myer, and S. Nakagawa, Extensional wave attenuation and velocity in partially-saturated sand in the sonic frequency range. Proceedings of the 38th U.S. Rock Mech. Symp., Washington, DC, pp. 141–145, 2001. Berkeley Lab Report LBNL-50831.

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